Data Collection and Monitoring of Stream-Channel Processes in Support of Numerical Models and Developing Water Quality Targets for Sediment

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Problem/Questions

- Stream/reach listed for sediment (303d)
- •Is stream/reach impacted/impaired?
 - 1. What are current sediment-transport rates and bedmaterial conditions?
 - 2. What are "background" or "reference" sedimenttransport rates and bed-material conditions?
 - 3. To apply BMPs: Where is the sediment coming from (fields, uplands, channels)?



Existing Sediment Load: AnnAGNPSplus CONCEPTS

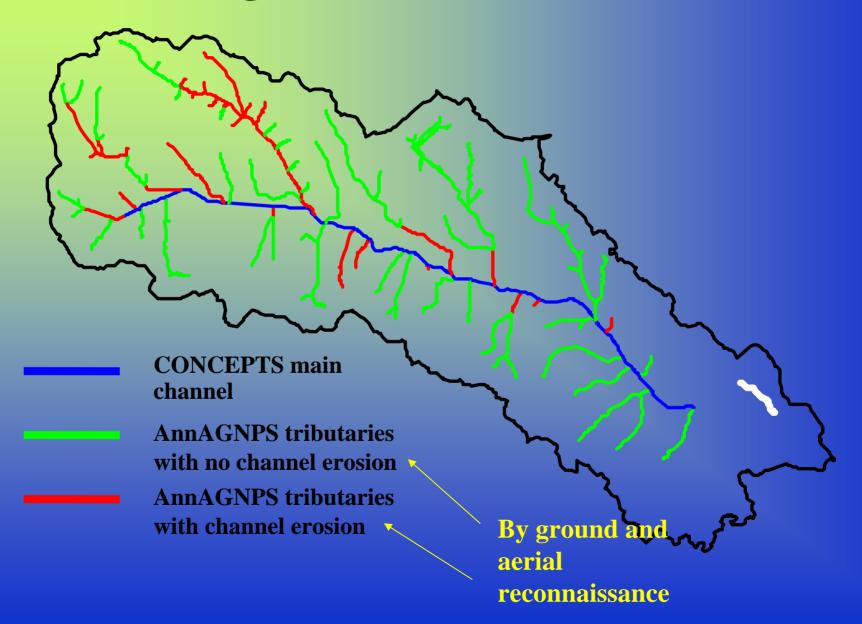
- Develop watershed boundary, network, and sub-drainage areas
- GIS-based watershed description of landuse and soils
- Develop weather database
- Produce flow and sediment loadings for input to CONCEPTS
- Collect boundary materials data for analysis of bed and bank processes
- Differentiate sources of sediment from fields and tributaries
- Calculate loads at 1.5 year recurrence interval to compare with "reference" loadings rates.



Talk will focus on channel modeling



Modeling Framework: James Creek



CONCEPTS – Conservational Channel Evolution and Pollutant Transport System

Channels respond to:

- Hydrologic changes
- Changes in sediment loadings
- Human intervention

Channels are dynamic, they adjust:

- Vertically: scour & fill, degradation & aggradation
- Horizontally: widening & migration

Models must capture these processes:

- Hydraulics
- Sediment transport and bed adjustment
- Streambank erosion (hydraulic and geotechnical)



(Langendoen, 2000)

CONCEPTS – Conservational Channel Evolution and Pollutant Transport System

(1-D Unsteady Flow)

Input:

- Channel geometry
- Composition of bed and bank materials
- Erosion resistance and shear strength of bed and bank materials
- Rates of flow and sediments entering the channel

Output:

- Changes in channel geometry
- Time series of hydraulic variables and sediment loads and concentrations







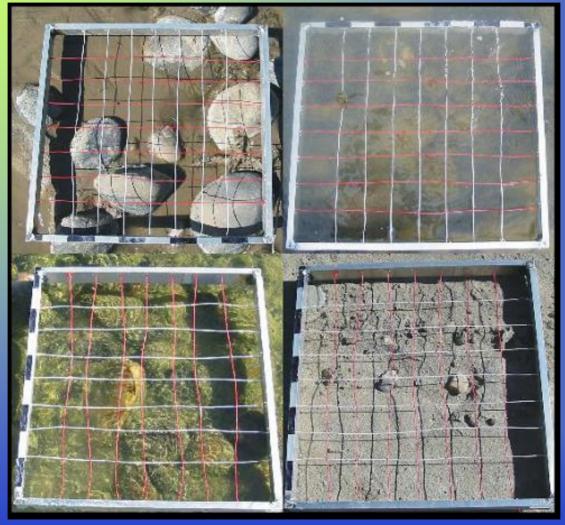








Non-Cohesives: Grid Sampling and Particle Counts





Erosion of Cohesives by Hydraulic Shear

Streambeds

Need a means to determine critical shear stress (τ_c) and the erodibility coefficient (k) in-situ for soils and sediments.





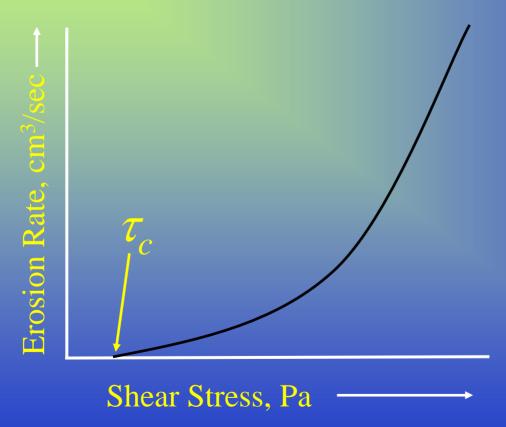
Cohesive Streambanks

- Jet-test device scours a hole in the bed or bank toe and measures the shear stress and erosion rate
- From this we calculate critical shear stress (τ_c)and erodibility coefficient, k



Measuring bank erodibility with the nonvertical jet test device

From Relation between Shear Stress and Erosion Rate: Calculate τ_c and k



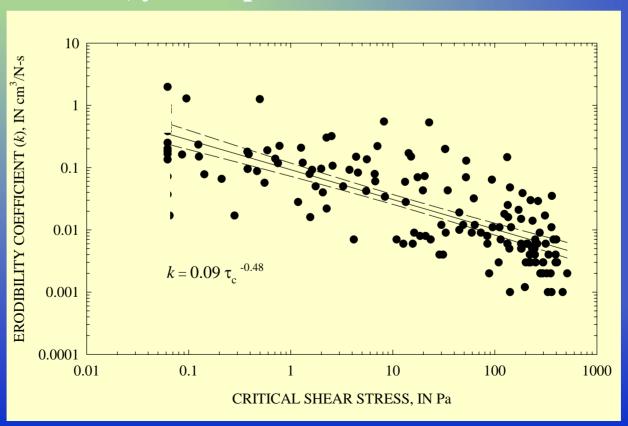


General Relation for Erodibility and Critical Shear Stress

Erodibility, cm³/N-s

$$k = 0.1 \tau_{\rm c}^{-0.5}$$

Where; τ_c = critical shear stress (Pa), x, y = empirical constants



Erosion Rate is a Function of Erodibility and Excess Shear Stress

$$\varepsilon = k (\tau_0 - \tau_c)$$

 $\varepsilon = erosion rate (m/s)$

Obtained from jet-test

 $k = \text{erodibility coefficient } (\text{m}^3/\text{N-s})^{\text{device}}$

 τ_0 = boundary shear stress (Pa)

 τ_c = critical shear stress (Pa)

 $\overline{(\tau_o - \tau_c)} =$ excess shear stress

Critical shear stress is the stress required to initiate erosion.

Bank Stability – The Factor of Safety

Factor of Safety
$$(F_s) = \frac{\text{Resisting Forces}}{\text{Driving Forces}}$$

If F_s is greater than 1, bank is stable. If F_s is less than 1 bank will fail.

Resisting Forces

soil strength

vegetation

matric suction

Driving Forces

bank angle

weight of bank

water in bank



Strength of Soil Materials

- Effective cohesion (high in clays, moderate in silts, absent in sands and gravels)
- Friction (high in sands and gravels, low in clays)
- Pore-water pressure the most dynamic variable

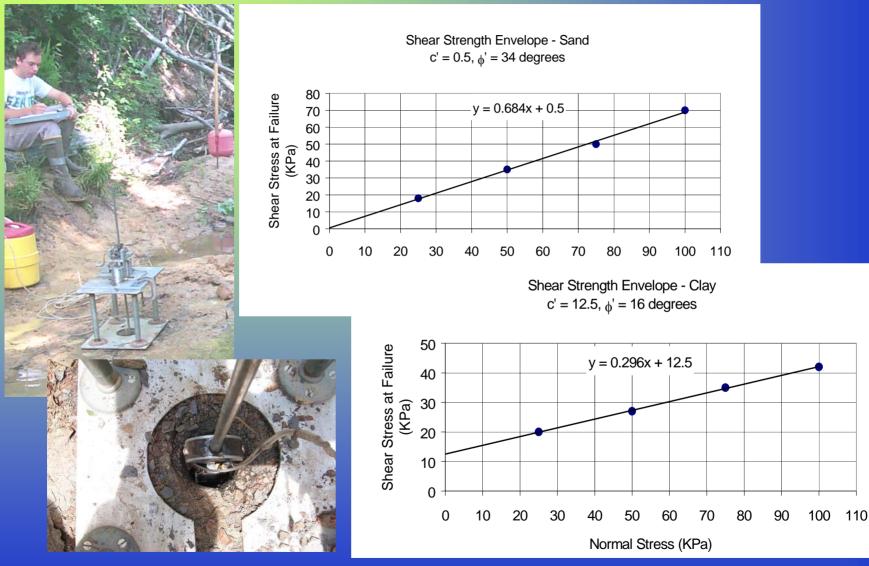
$$\tau_{\rm f} = c' + (\sigma - \mu_{\rm w}) \tan \phi'$$

where

 τ_f = shear strength (kPa); c' = effective cohesion (kPa); σ = normal load (kPa); μ_w = pore-water pressure (kPa) and ϕ' = effective friction angle (degrees).



Soil-Strength Testing



The Effects of Pore-Water Pressure

- Pore-water pressure reduces effective friction weakens the soil
- Increases weight of bank
- However, negative pore-water pressure (matric suction) increases bank strength
- Converting positive to negative pressure (lowering water table) increases strength



Incorporating Matric Suction as Apparent (total) Cohesion

$$\mathbf{c_a} = \mathbf{c'} + (\mu_a - \mu_w) \tan \phi^b$$

Where:

$$\begin{array}{rcl} c_a & = & apparent \ (total) \ cohesion \\ c' & = & effective \ cohesion \\ (\mu_a - \mu_w) & = & suction \ on \ the \ failure \ plane \\ \phi^b & = & angle \ representing \ the \ relation \\ & between \ the \ shear \ strength \ and \\ & matric \ suction \end{array}$$



Measuring Pore-Water Pressure

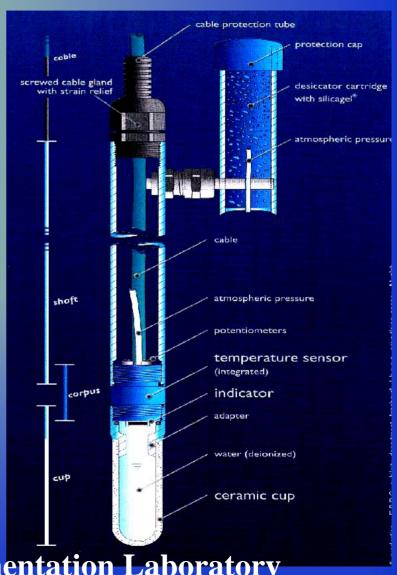
- Measure directly using tensiometers and piezometers
- Infer from water table height

$$\mu_{\mathbf{w}} = \mathbf{h} \, \gamma_{\mathbf{w}}$$

where

μ_w = pore water pressure (kPa);
 h = head of water (m);

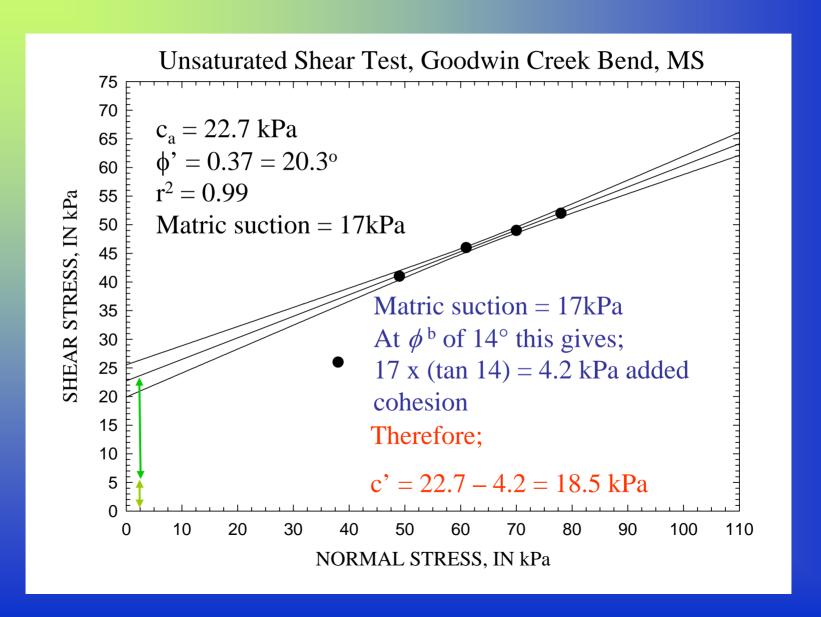
 $\gamma_{\rm w}$ = unit weight water (kN/m³)





National Sedimentation Laboratory

Incorporating Matric Suction



Measured Data

*Survey Cross-Sections		57
Main Channel (every 500m)		38
1967 Match	9	
Tributary	10	
*Bore-hole Shear Tests		38
*Vertical and Non-Vertical Jet To	ests	65
*Bed and Bank Material Samples		127
Bulk Density Samples	67	
Particle Size Samples	60	





Contribution to Annual Sediment Load from Fields and Channels: James Creek

1999 - 2002

89% Channels

11% Fields

1992 - 2002

70% Channels

30% Fields



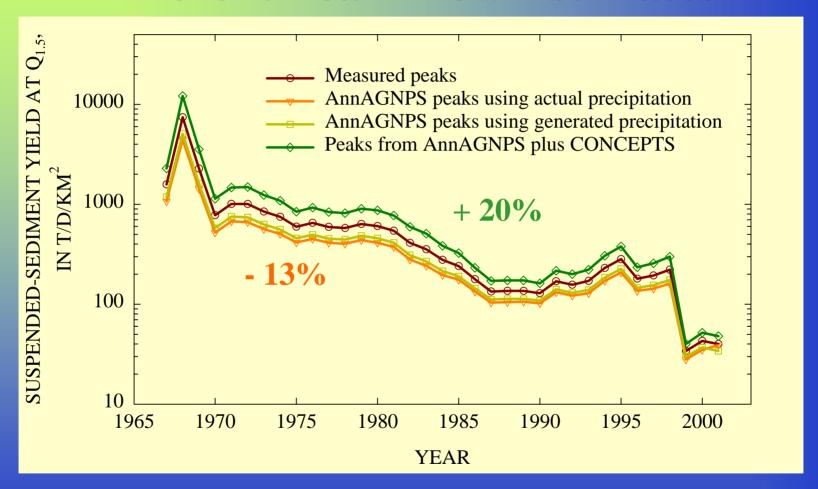


Units of "Reference": Tonnes/day/km²

- Subtract out gravel fraction from CONCEPTS 10-minute sediment-transport data.
- Develop sediment-transport curves from CONCEPTS output
- Determine "actual" sediment load at the effective discharge $(Q_{1.5})$
- •Divide by drainage area to obtain "actual" suspendedsediment yield at the effective discharge $(Q_{1.5})$



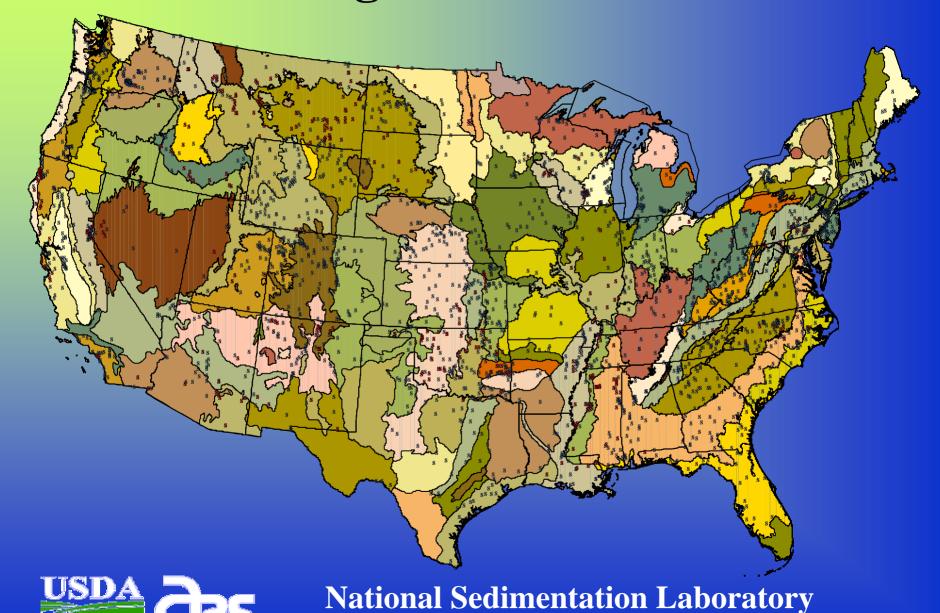
"Actual" Annual Yields at Q_{1.5} using Different Peak-Flow Estimates



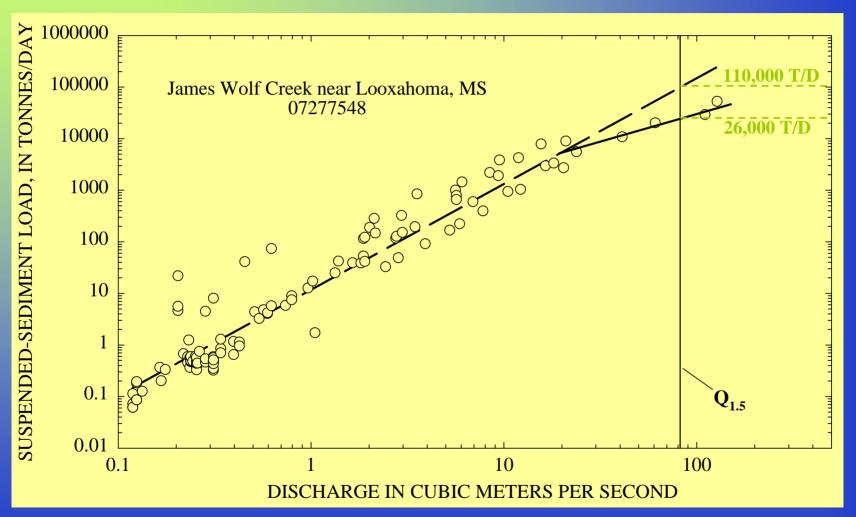




Level III Ecoregions and Available Data

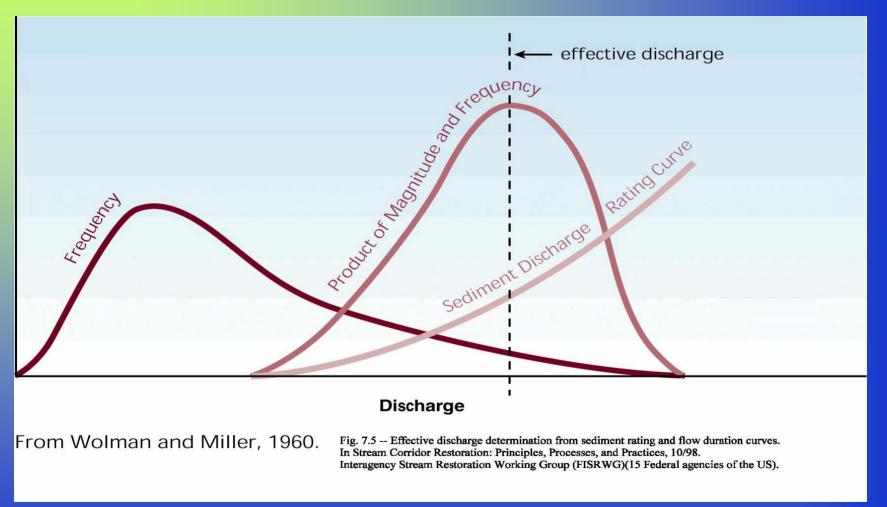


Two-Stage Suspended-Sediment Ratings



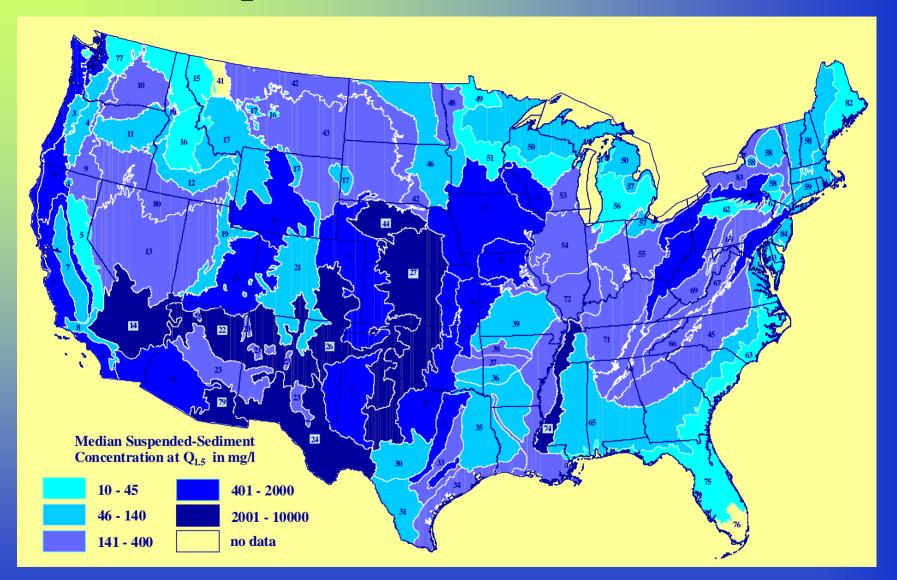


Definition Sketch of Effective Discharge



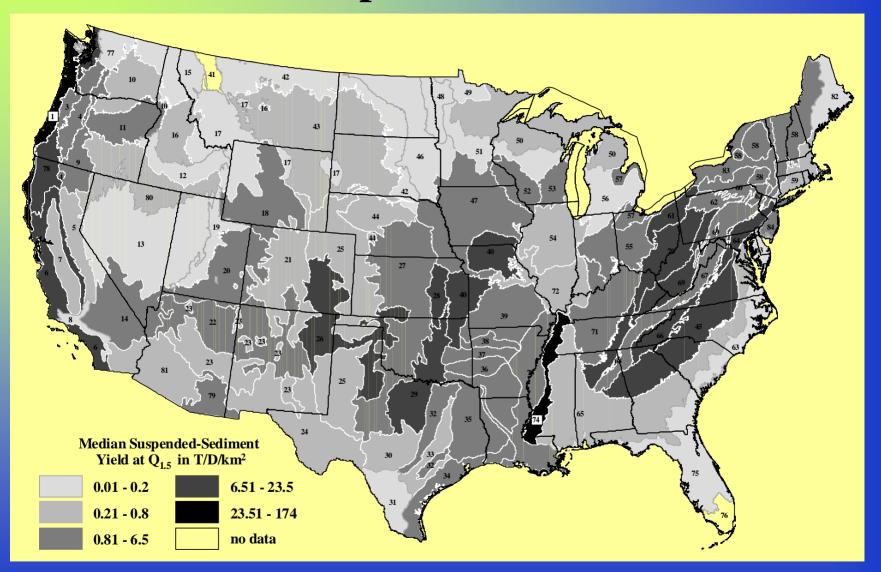


Median Suspended-Sediment Concentrations



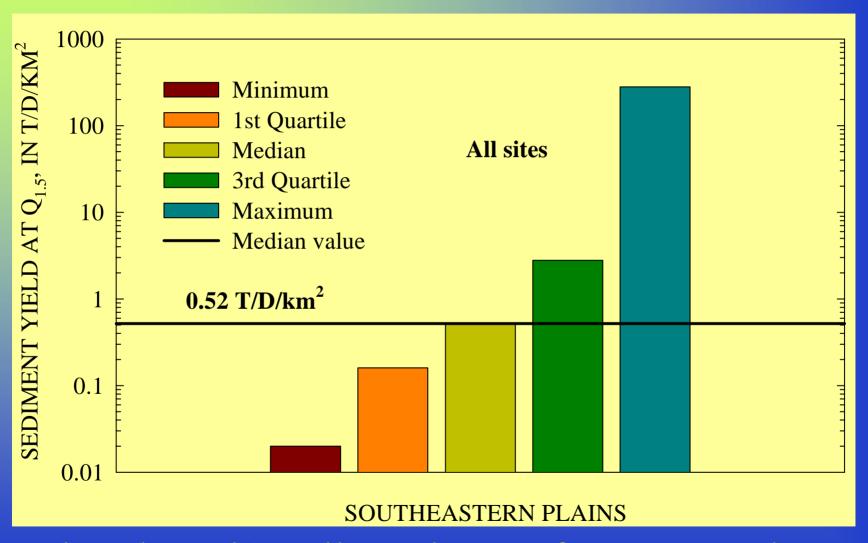


Median Suspended-Sediment Yields



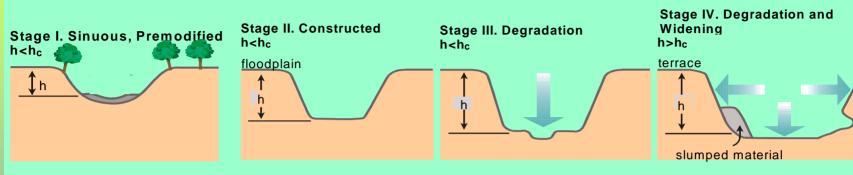


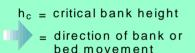
Suspended-Sediment Yields for the Southeastern Plains



What does this tell us about reference conditions?

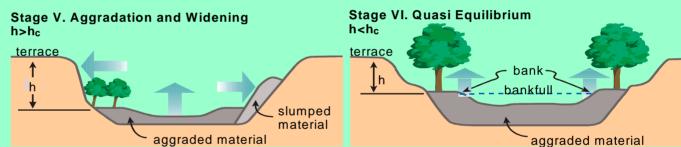
Stages of Channel Evolution (just another empirical model)

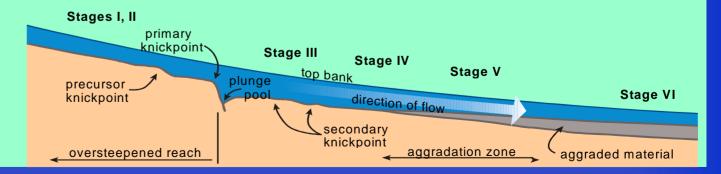




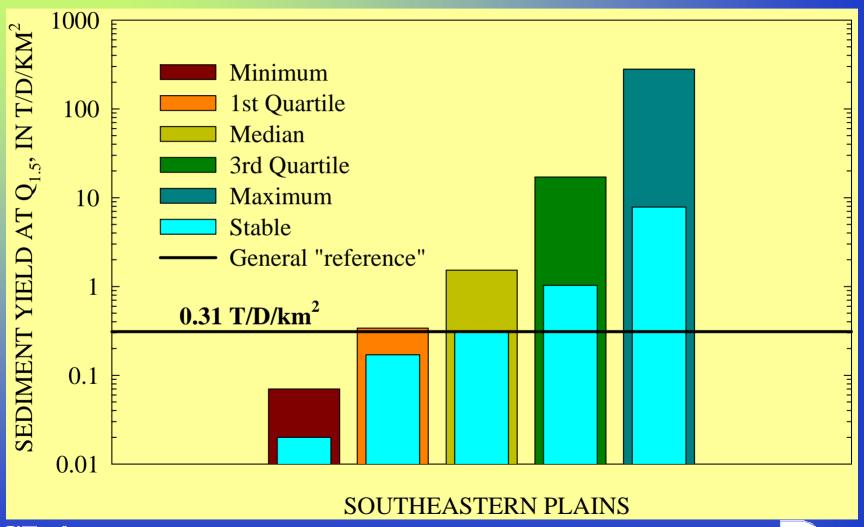
References

- •Stage I
- •Stage VI





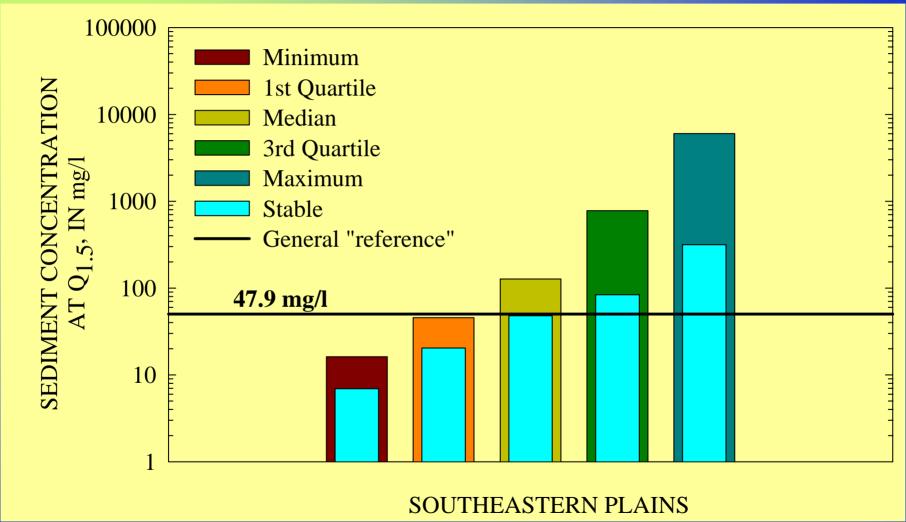
General "Reference" Suspended-Sediment Yield







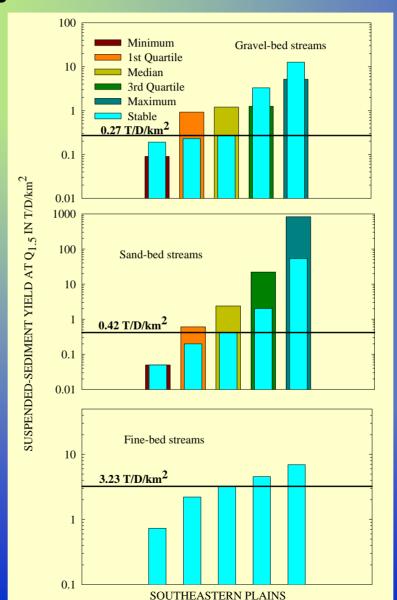
General "Reference" Suspended-Sediment Concentration







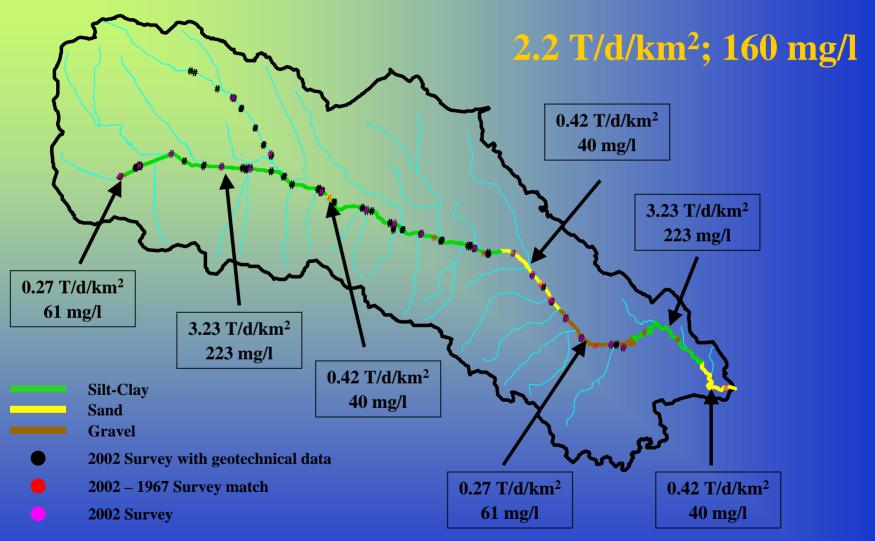
Refined "Reference" Suspended-Sediment Yields by Bed-Material Size Class







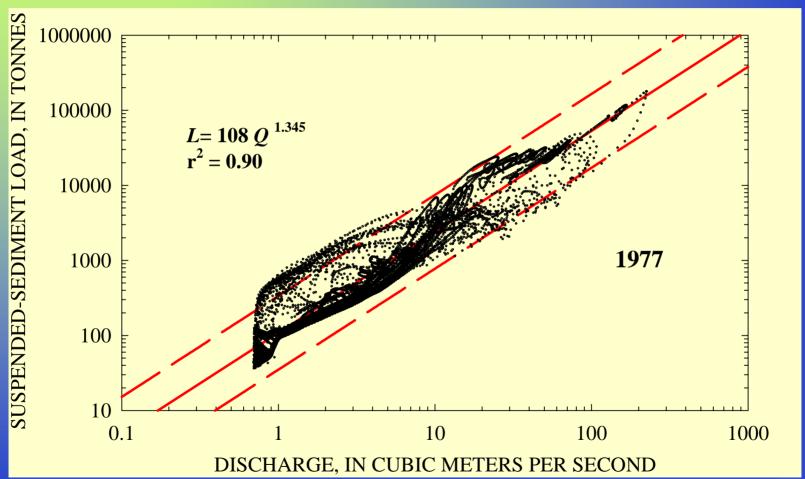
Weighting of "Reference" Values







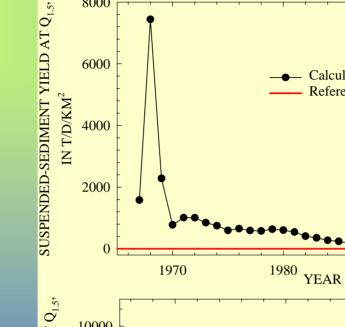
Example Sediment-Transport Relation Derived from CONCEPTS







"Actual" Annual Suspended-Sediment Yield at the Effective Discharge



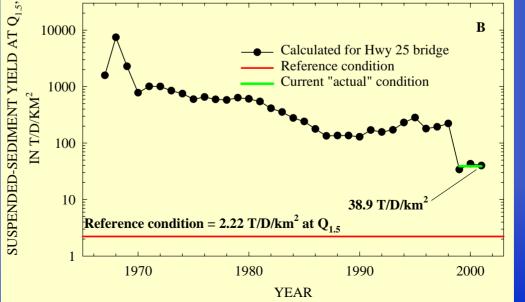
8000

6000

4000

IN T/D/KM²

Annual data







A

2000

Calculated for Hwy 25 bridge

1990

Reference condition